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Susceptibility of *Ceraeochrysa cubana* larvae and adults to six insect growth-regulator insecticides

Éric Kodi Ono, Odimar Zanuzo Zanardi*, Kenia Fernanda Aguiar Santos, Pedro Takao Yamamoto

Department of Entomology and Acarology, "Luiz de Queiroz" College of Agriculture/University of Sao Paulo (ESALQ/USP), 13418-900, Piracicaba, Sao Paulo, Brazil

HIGHLIGHTS

- The impact of six insect growth-regulators was assessed on *Ceraeochrysa cubana.*
- Diflubenzuron, lufenuron and pyriproxyfen were highly harmful to *C. cubana* larvae and adults.
- Pyriproxyfen was highly harmful to larvae and slightly harmful to *C. cubana* adults.
- Methoxyfenozide, tebufenozide and buprofezin were slightly harmful to *C. cubana* larvae.
- Methoxyfenozide, tebufenozide and buprofezin were harmless to *C. cubana* adults.

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ABSTRACT

The impacts of six insect growth-regulators were assessed on the predator *Ceraeochrysa cubana* (Hagen) larvae and adults. Our results showed that diflubenzuron, lufenuron and pyriproxyfen caused 100% larva mortality, whereas buprofezin, methoxyfenozide and tebufenozide were similar to control treatment. In comparison to the control, buprofezin prolonged the duration of larval stage, while methoxyfenozide and tebufenozide reduced the predator larva development time. Buprofezin, methoxyfenozide and tebufenozide did not affect the *C. cubana* duration and survival of pupal stage, fecundity and fertility. However, methoxyfenozide and tebufenozide reduced predator female and male longevities. Based on a reduction coefficient, diflubenzuron, lufenuron and pyriproxyfen were highly harmful to first instar larvae, while buprofezin, methoxyfenozide and tebufenozide were considered slightly harmful to the predator. Estimating the life table parameters, our results showed that buprofezin, methoxyfenozide and tebufenozide reduced the *C. cubana* R_o, r and λ. In comparison to the control, buprofezin prolonged the T and methoxyfenozide and tebufenozide shortened the predator T. In adults, our results showed that the insecticides did not cause significant mortality, but diflubenzuron, lufenuron and pyriproxyfen reduced the *C. cubana* fecundity and longevity. Diflubenzuron and lufenuron also reduced the *C. cubana* fertility. Based on a reduction coefficient, diflubenzuron and lufenuron were highly harmful to *C. cubana* adults, while pyriproxyfen was slightly harmful and buprofezin, methoxyfenozide and tebufenozide were considered harmless to the predator. Therefore, insect growth-regulators affect the *C. cubana* biological or populational parameters, and they can harm the integrated pest management programs that aim the predator conservation and/or augmentation in agroecosystems.

1. Introduction

The incidence of arthropod pests in agricultural production systems has been a main challenge for the crop productivity increase (Oliveira et al., 2013) due to damages caused on vegetative and reproductive structures, or by acting as pathogenic agent vectors that affect the normal development and reproduction of cultivated plants (Crawley, 1989). However, these herbivorous population control has been performed based on sequential spraying of wide-spectrum synthetic pesticides (Belasque et al.,

* Corresponding author. ESALQ/USP, Av. Pádua Dias, 11, Agronomia, CEP 13418-900, Piracicaba, Sao Paulo, Brazil.
E-mail address: odimarzanuzo@gmail.com (O.Z. Zanardi).

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2010). Although it is an important tool for the management programs of arthropod pests, and being easily used by growers with immediate results, many of these insecticides have been revoked due to human health and environmental contamination risks, low selectivity to benefic organisms (Cordeiro et al., 2010; Garzón et al., 2015), and prolonged residual period (Giolo et al., 2009; Nörnberg et al., 2011). Moreover, the overuse of these insecticides may accelerate the selection process of resistant populations to the active ingredients (Georghiou and Taylor, 1977), may induce the resurgence of the target pest (Dutcher, 2007; Guedes and Cutler, 2014; Guedes et al., 2016) and the outbreak of secondary pests as mites, aphids, scales and caterpillars (Cordeiro et al., 2013; Guedes et al., 2016). Most of the time, this situation requires additional pesticide applications, causing an increase in production costs and a reduction in efficiency of the management systems and environmental sustainability (Croft, 1990).

Due to all this, new insecticide groups were developed and used in management programs of several arthropod pests as alternative to the traditional neurotoxic insecticides (Agüero et al., 2014; Dhadialla et al., 1998; Meola and Mayer, 1980). Among the new insecticide groups, the insect growth-regulators have demonstrated high efficacy against insect pests, short residual period in environment, and reduced impact on superior animals (Dhadialla et al., 1998; Meola and Mayer, 1980; Tiwari et al., 2012). Furthermore, these insecticides have differential action mechanisms, acting as chitin-biossinthesis inhibitors, juvenil hormone analogous, or ecdystheroid receptor agonists, which are directly involved in ecdysis and growth processes of insects (Arthur et al., 2009; Meola and Mayer, 1980). Besides the high efficacy against several insect pests species, these insecticides have been considered more selective to natural enemies and compatible with the integrated pest management (IPM) programs (Liu and Chen, 2000). However, previous studies demonstrated that these insecticides can also affect the population growth of predators and parasitoids that act as biological control agents of insect pests (Biondi et al., 2015; Castro et al., 2012; Hatting and Tate, 1995; Magagula and Samways, 2000; Moscardini et al., 2013; Rugno et al., 2016; Yu et al., 2014). Besides the mortality, these insecticides can alter the biological (immature stage duration, fecundity, fertility and longevity) and behavioral parameters (mobility, orientation, search capability and mating) of natural enemies (Castro et al., 2012; Desneux et al., 2007; Liu and Stansly, 2004; Saber and Abedi, 2013), decreasing the biocontrol services in agroecosystems (Biondi et al., 2015).

Among the biological control agents, the generalist predator *Ceraeochrysa cubana* (Hagen) (Neuroptera: Chrysopidae) has been a main natural enemy in Neotropical agroecosystems (Albuquerque et al., 1994; Cordeiro et al., 2010; Rugno et al., 2015) due to its great reproductive capacity, voracity, search capability and ecological plasticity (Carvalho and Souza, 2009; Khuhro et al., 2014; Rugno et al., 2015). Its larvae have been associated with populations of aphids, scales, whiteflies, psyllids, and mites (Godoy et al., 2010; Michaud, 2004; Pappas et al., 2011; Quereshi and Stansly, 2007; Tauber et al., 2000) that cause considerable damages in several crops, including citrus (Carvalho et al., 2011; Rugno et al., 2015), mango (Barbosa et al., 2005) and melon (Bezerra et al., 2010). On the other hand, the adults feed on pollen, plant exudates and honeydew (Carvalho et al., 2011; Souza et al., 1996), allowing the predator survival and maintenance in agroecosystems during the period of low prey availability. In addition, it can be massively reared and released in smaller areas or greenhouse for the control of arthropod pests (Alcantra et al., 2008; Lopez-Arroyo et al., 1999).

Several studies have demonstrated the lethal and sublethal effects of insecticides on different lacewing species (Carvalho et al., 2011; Cordeiro et al., 2010; Maia et al., 2016; Rugno et al., 2015), but few reported the impacts of insect growth-regulators on *C. cubana* biological and populational parameters (Godoy et al., 2010; Rugno et al., 2016). Due to the *C. cubana* importance as a biological control agent of arthropod pests, and the need of studies that aim to improve the control tatic understanding in agroecosystems, this study assessed the compatibility of six insect growth-regulators commonly used in insect pest management in several crops on predator larvae and adults. These results will be important for the IPM programs because they can help in the understanding of the insecticide effects on *C. cubana* density and population dynamics. It can also contribute to the definition of future management strategies that aim the predator conservation and/or augmentation in production systems.

2. Material and methods

2.1. Insects

The *C. cubana* rearing was established in 2015 from specimens collected on Valencia sweet oranges [*Citrus sinensis* (L.) Osbeck (Rutaceae)] in an experimental grove on the campus of the "Luiz de Queiroz" College of Agriculture, Piracicaba, Sao Paulo, Brazil, where pesticides had not been applied in the preceding four months. The predator species was confirmed by Dr. Sérgio de Freitas from Universidade Estadual Paulista "Julio de Mesquita Filho" (UNESP), Jaboticabal, Sao Paulo, Brazil and the specimens were transferred to rearing cages made of polyvinyl chloride (PVC) with 10 cm in diameter $\times$ 20 cm in height with one end placed on an acrylic dish (15 cm in diameter $\times$ 0.5 cm in height) containing a filter paper disc in the base (15 cm in diameter); the other end was closed with a tulle screen as described by Rugno et al. (2015). The adults were fed with a mixture of brewer's yeast and honey (1:1, v:v) as proposed by Godoy et al. (2004). The food was available to the insects by means of cotton discs (3.5 cm in diameter) placed on the cages. To obtain the eggs, the cages were coated with white paper. The paper was replaced every 24 h and the eggs transferred to plastic pots of 1500 cm^3, with an opening ~7.5 cm in diameter (~41.2 cm^2) sealed with voile fabric. The hatched larvae were kept in the same plastic pots until the adults emerged. During this period, the larvae were fed *ad libitum* with *Ephestia kuehniella* (Zeller) (Lepidoptera: Pyralidae) eggs sterilized under a germicidal lamp (UV) as described by Stein and Parra (1987). The rearing was kept in a climate-controlled room at a 25 $\pm$ 2 °C temperature, 70$\pm$ 10% relative humidity (RH), and 14 L: 10 D h photoperiod. To perform the bioassays, fifth-generation larvae and adults maintained under laboratory conditions were used.

2.2. Chemicals

Six commercial formulations of insecticides were assessed on *C. cubana* larvae and adults, representing the main compounds belonging to the insect growth-regulator group used in agricultural fields in Brazil. All compounds were tested at the label rates recommended for the management of caterpillars, aphids, scales, whiteflies, and psyllids at the Ministry of Agriculture, Livestock and Supply (MAPA, 2015). The tested active ingredients and concentrations, and the action mode (IRAC, 2016) were as follows: diflubenzuron 0.12 g a.i. L^{-1}, chitin-biosynthesis inhibitors type 0 (Micromite 24%, w/v suspension concentrate; Chemtura Indústria Química do Brasil Ltda.), lufenuron 0.25 g a.i. L^{-1}, chitin-biosynthesis inhibitors type 0 (Match 5%, w/v emulsifiable concentrate; Syngenta Crop Protection Ltda.), buprofezin 0.50 g a.i. L^{-1}, chitin-biosynthesis inhibitors type 1 (Applaud 25%, w/w soluble powder; Arysta Lifescience of Brazil Chemical Industry and Agriculture), methoxyfenozide 0.75 g a.i. L^{-1}, ecdysteroid receptor